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Chemical Fingerprinting of Plants from Contrasting Wetlands - Salt Marsh, Geothermal and Mining-impacted

By

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K e y w o r d s : Geothermal springs, arid regions, mining, salt marsh, *Triglochin maritima*, *Rumex pamiricus*, *Phragmites australis*, New Mexico, Kyrgyz Republic, Ireland.

S u m m a r y

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The elemental content (up to 57 elements) of sediments and plants (*Phragmites australis*, *Rumex pamiricus* and *Triglochin maritima* from wetlands contrasting in element composition (mining area, geothermal spring, salt marsh) from a wide geographic range (USA, Ireland, Kyrgyz Republic) was investigated. The element composition of the plants did not reflect that of the sediments. Comparison to Markert's 'reference plant' showed that the concentrations of B, Ba, Co, Cu, Ga, Mg, Mn, Pb, Rb, Sr, Y, Zn and most lanthanides were very similar (less than threefold variation) among the three species, regardless of origin. The elements Na, Th and U were accumulated to much higher levels than the 'reference plant' in all three species, indicating their potential for phytoremediation and phytomining purposes.

I n t r o d u c t i o n

The great majority of studies on elemental uptake in plants has focused on a very limited number of elements, partly due to (1) a lack of suitable analytical techniques, at least until relatively recently, and (2) a perception that the majority of natural elements are not essential and thus unimportant from an agricultural and human nutrition perspective. As a result, much knowledge has been gathered about recognized essential nutrients and/or potentially toxic elements, such as N, P, K, Fe, Cu, Zn, Cd and Pb. This does not mean, however, that elements that have not

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been proven to be essential to plants are not essential, nor that they could not reach toxic concentrations. An example is the group of the rare earth elements (REEs), which includes the lanthanides. These are not considered essential for growth, yet increasingly research reports emerge showing that plants benefit from fertilization with REEs (e.g. HE & LOH 2000, XU & al. 2002). This is one reason why the much improved availability and sensitivity of analytical techniques such as Neutron Activation Analysis (NAA) and Inductively Coupled Plasma analysis (ICP) should be utilized for research on multi-element uptake and translocation of plants. Another reason is that industrial emissions of elements that have so far received little attention have increased over the past decades and information about their environmental impacts and ecotoxicological effects is much needed (WELTJE & al. 2002).

In recent years we have collected plant and sediment samples from wetlands which were quite different from each other, except for one common feature: they were highly enriched in certain elements that are not normally encountered in high concentrations in the majority of wetlands. We also collected plants and sediments from comparable non-enriched wetlands. Samples were taken from (1) a high altitude, arid region near Issyk-Kul, a lake in the Kyrgyz Republic, Central Asia, (2) from wetlands associated with hot, hydrothermal springs in New Mexico, USA, and (3) from a salt marsh in Ireland. Two plant species, *Rumex pamiricus* and *Phragmites australis,* were collected from a uranium mining impacted stream and from a non-impacted stream in the Kyrgyz Republic. *Triglochin maritima* was collected from the sites in New Mexico and Ireland. The plants were therefore collected from a wide geographical range.

The samples were analyzed for up to 57 elements. As is already implicated above, for most elements present in the substrate in non growth-limiting quantities a relationship between concentrations in plants and sediments under natural conditions is typically not found (OTTE & al. 1993, O'CONNOR & PAUL 2000, REIMANN & al. 2001, OTTE 2004). However, information about variation in element concentrations across species and regions, particularly concerning less-studied elements is not widely available. Here we use the dataset to address the following questions and hypotheses.

Despite the wide geographical range and differences between the plants, can patterns regarding elemental uptake and distribution be discerned that are common to all three species and from all sites? Most studies on elemental uptake and distribution in plants have focused on agricultural and ecotoxicological questions, that is whether or not elements are present in growth-limiting (crops) or toxic (ecotoxicology, animal and human health) amounts. Information about similarity in elemental composition of plants is difficult to find, the study by REIMANN & al. 2001 being an exception, yet such information is equally important for our understanding of elemental uptake and transfer to higher trophic levels. Based on the work by REIMANN & al. 2001 it was expected that elements like Co, Pb, Ba and Y would show significant variation between species and sites, while concentrations of elements like Rb, S, Cu, K, Ca and Mg would show great similarity.

Are there elements that are accumulated in the plants to concentrations above 'normal' levels? Such questions require comparisons of plants to a 'normal'

control. In this study that purpose was served by comparing the element content of our samples with reference material using the 'chemical fingerprinting' technique developed by Markert and co-workers (MARKERT 1992, DJINGOVA & al. 2004). In this approach the elemental composition of a sample plant is compared to that of the 'reference plant' - empirically determined values for elemental concentrations based on the average composition of plants. The elements are grouped and ordered according to their known functions in plants (e.g. structural, such as C, N, P and S, or enzymatic, such as Co, Fe Zn) and/or to their chemical similarities (e.g. the lanthanides La-Lu). Such a comparison is valuable, as it provides a standardized baseline against which other plants can be compared. Deviations from values of the reference plant may indicate plants that could be suitable for biomonitoring, prospecting, phytoextraction or phytomining purposes (MARTIN & COUGHTREY 1982, SALT & al. 1995). We had no clear expectations beforehand which elements in particular might be accumulated by the plants, but the null hypothesis was that elemental composition of the plants would not vary from that of the 'reference plant' of MARKERT 1992. The exception was *Triglochin maritima*, which, being a saltmarsh plant, was expected to accumulate concentrations of Na higher than the 'reference plant'.

Material and Methods

Site descriptions, sampling procedures and preparation of samples for chemical analysis

Issyk-Kul, Kyrgyz Republic

The data presented here were obtained as part of a larger research project in the area along the southern shore of Issyk-Kul entitled 'Ecology of Water Bodies and the State of Health of the Population in the Region of the South-Eastern Part of Issyk-Kul Lake', funded by INTAS (http://www.ucd.ie/kyr/kyrhome.htm). The lake is situated in the Kyrgyz Republic at about 42°N latitude and between 77° and 78°E longitude in the northern Tien-Shan mountains at an elevation of 1606 m. The grass *Phragmites australis* (Cav.) Trin. ex Steud. was commonly found in association with the dicotyledon *Rumex pamiricus* Rech. f. in wetlands along streams up to an elevation of about 2400 m. Sampling of plants and sediments took place between 26 July and 3 August 1999. Seven streams of varying size were investigated in the entire project, but only data from the Tossor River (N42° 05' E77° 22', elevation of sampling sites between 1608 and 2090 m) and one small stream, the Juluu Bulak (N42° 09', E77° 13', elevation of sampling sites between 1670 and 1675 m), will be presented here. The Tossor River has no known history of anthropogenic impacts other than low-intensity grazing during the summer months and extraction of drinking water for a small village near the lake. The Juluu Bulak on the other hand is a small stream emerging from the tailings of an abandoned (1950s) uranium/lignite mine near the town of Kadji-Sai.

From each sampling site three samples of each plant species with sediments attached to the roots were taken with a trowel and transported to our expedition headquarters at the 'Zorka' resort near Bakonbaevo. On the same day the sediments were separated from the plants and laid out on plastic bags to be air-dried (no other suitable facilities for drying samples were available on site). Leaves of the plants were taken, washed with water and laid out to be air dried on paper bags. At the end of the three-week expedition, soils and leaves of plants were packed in paper bags, which were then packed in plastic bags and shipped to our laboratory in Dublin, Ireland. Upon return to the laboratory in Dublin all samples were dried until constant weight at 60°C. Leaves were ground and homogenized in liquid nitrogen in a mortar and pestle. Sediment samples were homogenized and sieved through a 90-µm sieve.

Soda Dam, New Mexico, USA

Soda Dam is a hot spring in the Jemez River valley in the north of New Mexico, U.S.A. (N35° 47', W106° 41', elevation 1,920m). The name refers to the natural dam formed in the Jemez River by the deposition of carbonates. *Triglochin maritima* is the only emergent macrophyte found growing in the water originating from the spring.

Sediment temperatures between the roots of the plants varied between 27 and 40 °C. Samples of plants and sediments adhering to the roots were collected on 23 April 2003, air-dried and transported in paper bags to the lab in Ireland. Upon return to the laboratory in Dublin all samples were dried until constant weight at 60°C. Leaves were ground and homogenized in liquid nitrogen in a mortar and pestle. Sediment samples were homogenized and sieved through a 90-µm sieve.

North Bull Island, Dublin Bay, Ireland

North Bull Island is a barrier island in Dublin Bay, Ireland (N53° 17' W6° 5', elevation 0-3 m). The sampling sites were located in a salt marsh on the landward lagoon side of the island. *Triglochin maritima* is found in a vegetation zone in association with other typical saltmarsh species, such as *Halimione portulacoides*, *Aster tripolium*, *Armeria maritima* and *Limonium humile*. Samples of plants and sediments adhering to the roots were collected on 11 October 2003. Upon return to the laboratory in Dublin all samples were dried until constant weight at 60°C. Leaves were ground and homogenized in liquid nitrogen in a mortar and pestle. Sediment samples were homogenized and sieved through a 90-µm sieve.

Chemical analysis

NAA and ICP analyses

All samples were sent to Activation Laboratories Ltd., Lancaster, Ontario, Canada, for elemental analyses. Sediments were analysed by Instrumental Neutron Activation Analysis (INAA) and/or Induction-Coupled Plasma - Optical Emission Spectrometry (ICP-OES) after total 'four-acid' (HF, $HCLO_4$, HCL, HNO_3) digestion. All plant samples were analysed by Induction-Coupled Plasma - Mass Spectrometry (ICP-MS) after low-temperature ashing an acid digestion. The accuracy of the analyses was tested using standard reference materials appropriate to the sample matrices and values were within the acceptable range for each element. See also www.actlabs.com.

Loss-on-Ignition

Sediment samples (5 g) from all sites were weighed into ceramic crucibles and ashed at 550 °C for at least 6 hours. Weight loss upon ashing was expressed in g $100g^{-1}$.

Data analysis

Sediments

Because the difference in element concentrations between 'Phragmites' and 'Rumex' sediment samples from the same sampling sites in the Kyrgyz Republic were only marginally different, these were regarded as replicate samples. The number of observations varied between Tossor and Juluu Bulak. Because the Tossor is a much longer river than the Juluu Bulak and because the choice of sampling sites was restricted to areas that had vegetation containing the species of interest, nine sediment samples were sampled with each of the two species along the Tossor (thus n=18) against three (n=6) along the Juluu Bulak. Only mean values for each stream, pooling all available observations, are presented here.

Plants

The element concentrations in the plants were calculated as values relative (%) to the 'reference plant' as

$\frac{(Xsample - Xref)}{Xref} \times 100$ in which *Xsample* is the concentration of the element in the sample, and *Xref* is the concentration of the 'reference plant' (MARKERT 1992), see Table 1.

Table 1. Content of selected elements of the 'reference' plant (MARKERT 1992).

Element	Concentration (mg kg^{-1} dry weight)	Element	Concentration (mg kg^{-1} dry weight)
Cr	1.5	Te	0.05
Cu	10	Cd	0.05
Fe	150	Sc	0.02
Mn	200	Bi	0.01
Mo	0.5	Se	0.02
Ni	1.5	Y	0.2
V	0.5	La	0.2
Zn	50	Ce	0.5
Li	0.2	Pr	0.05
Na	150	Nd	0.2
K	19,000	Sm	0.04
Rb	50	Eu	0.008
Cs	0.2	Gd	0.04
Be	0.001	Tb	0.008
Mg	2,000	Dy	0.03
Ca	10,000	Ho	0.008
Sr	50	Er	0.02
Ba	40	Tm	0.004
B	40	Yb	0.02
Al	80	Lu	0.003
Ga	0.1	Th	0.005
In	0.001	U	0.01
Tl	0.05	Ti	5
Ge	0.01	Hf	0.05
Pb	1	Nb	0.05
As	0.1	Ta	0.001
Sb	0.1	W	0.2

Results

Sediments

The loss-on-ignition (LOI) and element concentrations in sediments are given in Table 2: As indicated by LOI, organic matter content of the Kyrgyz sites was very low. Organic matter content at Soda Dam, NM, was 2-4 times higher than at the Kyrgyz sites, while at North Bull Island the highest value was found at about four times that of Soda Dam. The overall distribution of the elements, i.e. comparing the element concentrations relative to each other, was similar across all sampling sites, with Al, Ca, Fe, K, and Mg present in the highest concentrations. The

Kyrgyz Republic 'Phragmites/Rumex' sampling sites were more similar to each other, with 22 of the 39 elements varying less than two-fold between the two streams, than the New Mexico/Ireland 'Triglochin' sites, which showed about half of the element concentrations, 28 out of the 57, varying less than two-fold between the sites. Concentrations of As, Cs, Cu, Mo, Ni, Pb, Sb and W were at least two times higher along the Juluu Bulak than along the Tossor, while the reverse was true for Ce, Hf, La, Mg, Nd, Sc, Sm, Ti and Y. Almost half of the 57 elements analysed were present in at least twice higher concentrations in the New Mexico hot spring samples compared to the Irish North Bull Island salt marsh samples: Al, Ba, Bi, Ca, Cd, Eu, Fe, Hf, In, K, La, Mn, Mo, Na, Nd, Pb, Pr, Sb, Sm, Sr, Te, Th, Ti, Tl, V, and Zn. The reverse, concentrations being at least two times greater in the Irish salt marsh compared to the New Mexico hotspring was true for Cs, Sc, Se and W. For most elements concentrations in the sediment samples from the Kyrgyz Republic were higher compared to the New Mexico/Ireland samples, including Na. Notable exceptions were S and Ti, the latter being high particularly in the New Mexico hot spring samples.

Table 2. Loss-on-Ignition (g $100g^{-1}$) and element concentrations (mg kg^{-1} dry weight) in sediments of wetlands along streams in the Kyrgyz Republic (Juluu Bulak, Tossor), associated with a hot spring in New Mexico, USA (Soda Dam) and in a salt marsh in Ireland (North Bull Island). - = element not analyzed in this study, n.d. = non detectable, i.e. below the detection limit of the method.

	Juluu Bulak (n=6)	Tossor (n=18)	Soda Dam (n=5)	North Bull Island (n=3)
LOI (g $100g^{-1}$)	1.15	2.18	5.4	20.1
Element				
Al	63,092	71,517	18,290	8,737
As	17	8	11	18
B	-	-	1.1	1.0
Ba	710	820	280	45
Be	2.0	2.6	2.4	2.3
Bi	n.d.	n.d.	0.9	0.4
Ca	72,192	38,423	10,308	5,063
Cd	n.d.	n.d.	0.35	0.11
Ce	75	174	45	25
Co	11.5	15.1	4.2	2.4
Cr	62	34	21	13
Cs	25	9	6	16
Cu	75	21	75	50
Dy	-	-	1.5	1.0
Er	-	-	0.8	0.5
Eu	1.19	2.16	0.46	0.15
Fe	29,500	58,339	21,766	10,040
Ga	-	-	4.7	3.3
Gd	-	-	2.4	1.3

Ge	-	-	0.8	1.0
Hf	9.5	29.7	0.3	0.1
Ho	-	-	0.28	0.19
In	-	-	0.05	0.02
K	20,342	24,428	5,996	1,650
La	42	88	22	10
Li	-	-	14	18
Lu	0.59	1.11	0.12	0.12
Mg	6,542	13,311	3,452	1,990
Mn	777	1097	630	279
Mo	4.35	2.00	2.43	0.96
Na	11,284	17,556	2,378	320
Nb	-	-	5	4
Nd	30	75	17	8
Ni	22	13	11	6
Pb	57	32	102	18
Pr	-	-	4.6	2.3
Rb	140	145	46	22
S	642	761	2,041	3,697
Sb	2.6	1.0	0.9	0.2
Sc	10.50	24.20	0.01	0.02
Se	n.d.	n.d.	0.8	1.9
Sm	6.0	15.1	3.1	1.5
Sn	n.d.	n.d.	7.1	8.2
Sr	218	217	73	27
Ta	1.55	2.65	0.05	0.05
Tb	0.9	1.8	0.3	0.2
Te	-	-	0.15	0.04
Th	22	32	5	1
Ti	2,384	5,200	13,346	3,217
Tl	-	-	0.6	0.2
Tm	-	-	0.1	0.1
U	12	11	7	7
V	71	91	32	10
W	147.6	10.3	0.7	1.6
Y	24	64	8	5
Yb	3.8	7.6	0.8	0.7
Zn	92	114	138	44

Plants

P. australis and *R. pamiricus* from the Kyrgyz Republic

Along both the Tossor and the Juluu Bulak, *P. australis* contained at least five times (500%) higher concentrations of Li, Na and Th compared to the 'reference plant' (Fig. 1). In addition, along the Tossor only, concentrations of Mo and As were strongly elevated. Along the Juluu Bulak only concentrations of Cs, Be,

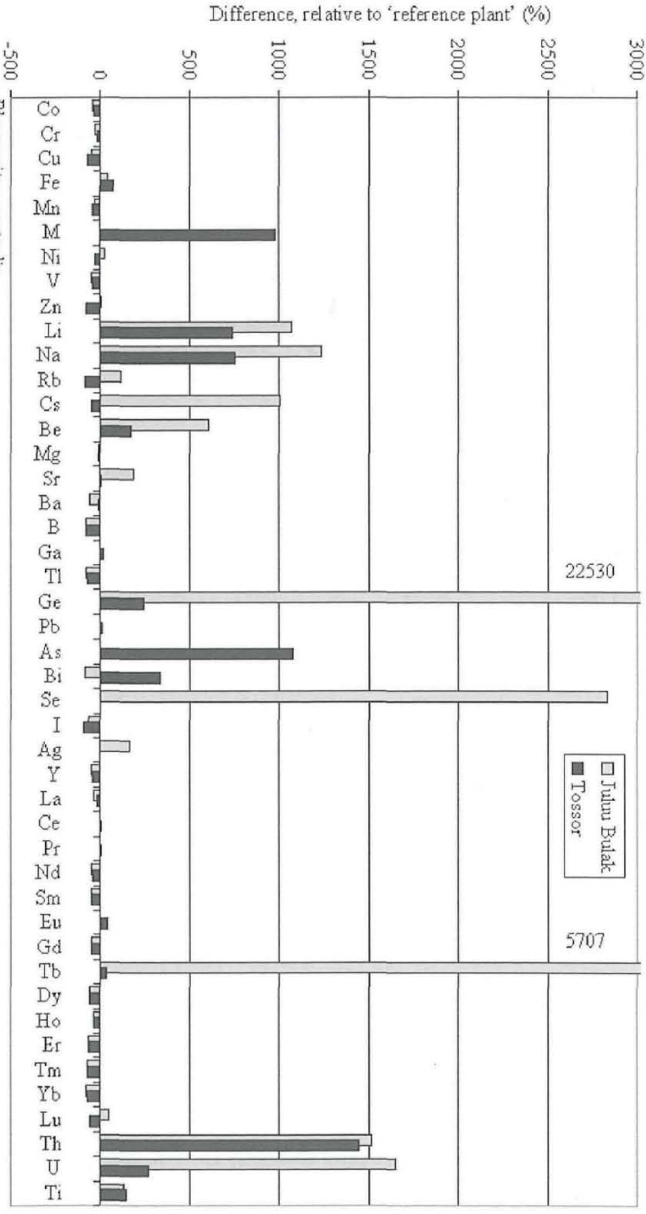

Fig. 1. Chemical fingerprint, the average difference between the sampled plants and the 'reference plant' of MARKERT 1992 as a percentage of the 'reference plant' values, for *Phragmites australis* from the Juluu Bulak (n=3) and Tossor (n=9).

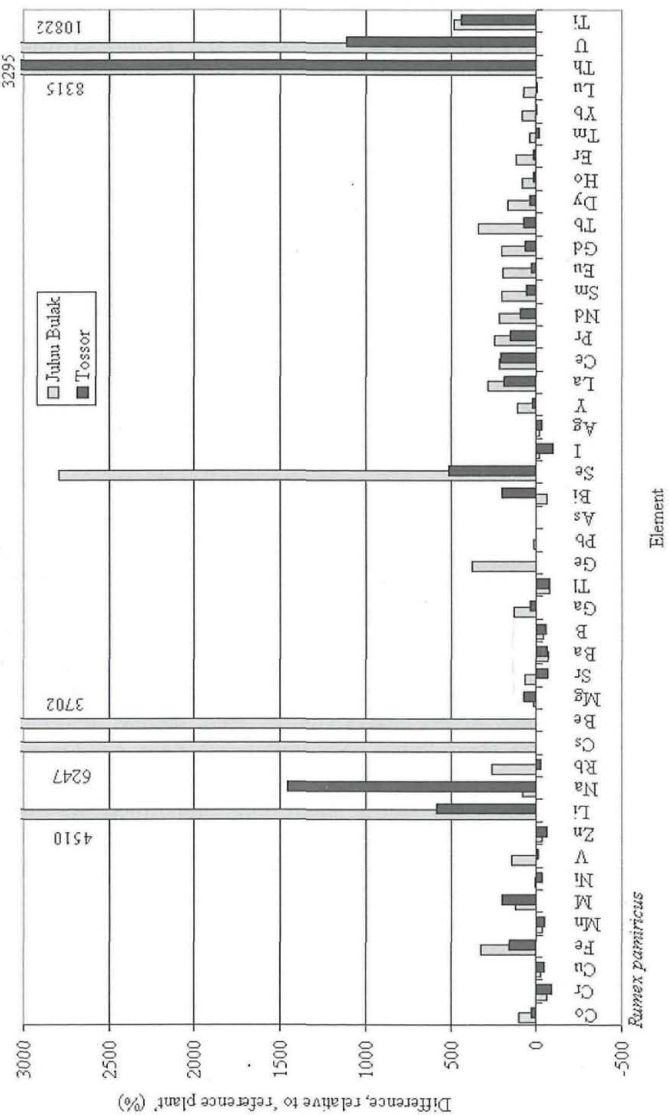

Fig. 2. Chemical fingerprint, the average difference between the sampled plants and the 'reference plant' of MARKERT 1992 as a percentage of the 'reference plant' values, for *Rumex pamericus* from the Juluu Bulak (n=3) and Tossor (n=9).

Ge, Se, Tb and U were at least five times higher than in the 'reference plant'. While several other elements were somewhat elevated compared to the reference plant, most elements in *P. australis* were present in somewhat lower concentrations.

R. pamiricus (Fig. 2) contained more than five times the 'reference plant' values of Li, Se, Th along both streams. Ti concentrations in *R. pamiricus* reached almost similarly elevated values along both streams. Along the Tossor only, Na values in *R. pamiricus* were at least five times higher than in the 'reference plant', while this applied to Cs and Be for plants along the Juluu Bulak only.

Overall, *R. pamiricus* for many elements contained higher concentrations than *P. australis*, particularly for the elements of the lanthanide series La-Lu, a notable exception being Tb.

T. maritima from Ireland and New Mexico, USA

At both sites, *T. maritima* contained more than five times higher concentrations of Li, Na, Be, In and As than the 'reference plant'(Fig. 3). At Soda Dam only, the plants also contained at least five times higher concentrations of Fe, Cs, Tl, Ge, Sb, Sc, Th, U and W. The plants from Soda Dam generally contained higher elemental concentrations than those from Ireland.

Discussion

The element concentrations in the sediments are presented here to give a general indication of the differences and similarities between the sites, not to draw conclusions about availability of elements for uptake by plants or about differences in natural or anthropogenic enrichment. It is well known that total concentrations of elements do not give information about bioavailability, but at the same time there is no agreement on how to reliably assess bioavailability under natural field conditions (O'CONNOR & PAUL 2000, OTTE 2004). For similar reasons it is not possible to reliably distinguish between natural and anthropogenic enrichment of elements (REIMANN & DE CARITAT 2004). Nonetheless, interesting similarities and differences were observed in the elemental composition of the different sediments. One striking and counter-intuitive difference between the Kyrgyz sites on the one hand and the New Mexico/Irish sites on the other is in the Na concentrations. As the name suggests, Soda Dam is sodium-rich, as is the salt marsh of North Bull Island, yet both show much lower Na concentrations in the sediments than the Kyrgyz sites. This could be partly explained by differences in organic matter content, but the more likely explanation is that while the water in both systems contained high Na concentrations, the sediments in which the plants grew did not. In the Irish salt marsh, the sediments most likely originate from the Irish mainland, and so not necessarily derived from Na-rich bedrock. The soil water salinity, particularly in the zone occupied by *Triglochin maritima*, fluctuates enormously - around the concentration of seawater (500-600 mM) during periods of flooding, much higher concentrations during periods of drought and much lower during periods of rainfall

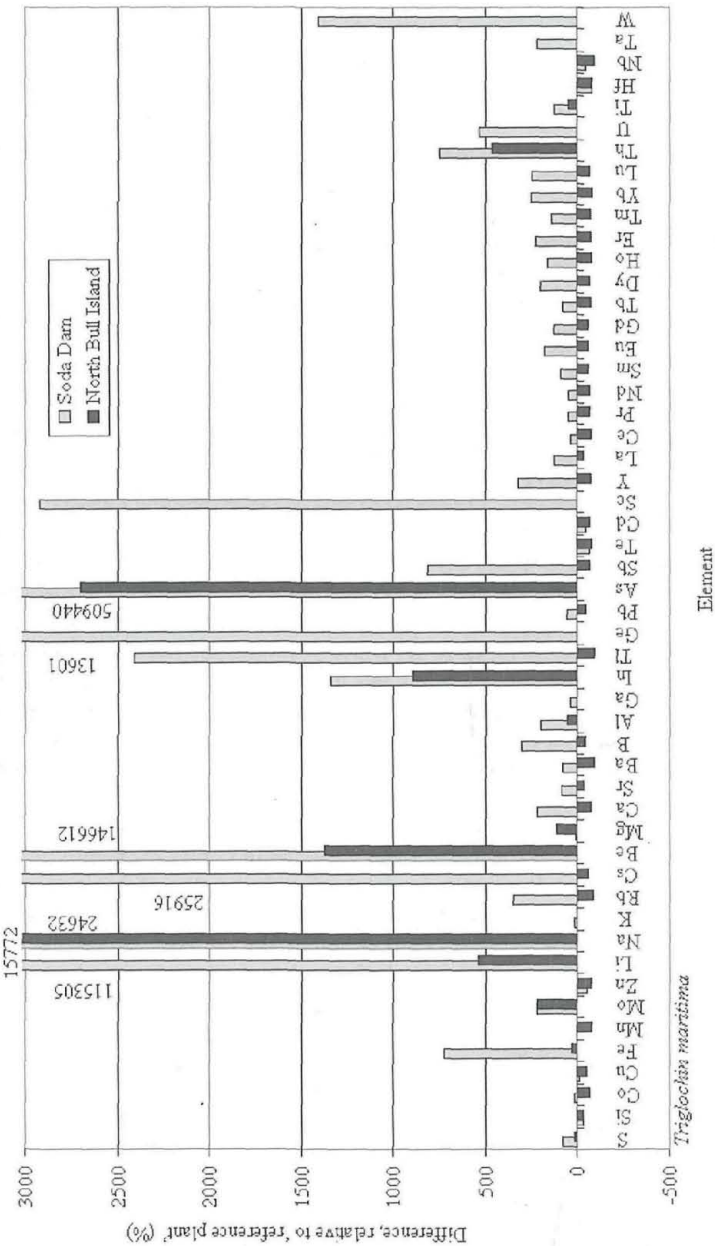

Fig. 3. Chemical fingerprint, the average difference between the sampled plants and the 'reference plant' of MARKERT 1992 as a percentage of the 'reference plant' values, for *Triglochin maritima* from the Soda Dam, New Mexico (n=5) and North Bull Island, Ireland (n=3).

(ADAM 1990). Because Ireland has a humid climate with relatively high rainfall throughout the year, it is very likely that the salinity at the time of sampling was relatively low. Similarly at Soda Dam, although the water originates from a Na-rich spring, this does not necessarily mean that the sediments surrounding the roots were rich in Na.

While the New Mexico hot spring and the Irish salt marsh are entirely different systems, separated by thousands of kilometers, the Kyrgyz streams were much closer to each other and emerge from the same mountain range. Yet at least half the elements showed less than two-fold ranges in sediment concentrations when comparing the Kyrgyz sites or the New Mexico hot spring with the Irish salt marsh. Conversely, the widest range in sediment element concentrations was displayed by W, 14-fold between the two Kyrgyz sites, as opposed to about 2-fold between the New Mexico and Irish sites. This highlights that sites within close proximity and with similar geological backgrounds can vary greatly in content of certain elements while the opposite is true as well: sites that are geographically remote and of entirely different geological origin can be very similar in elemental content. This further indicates that from the point of view of elemental uptake by plants, similarity of sites should not be assessed based on their proximity or geological characteristics, but on the occurrence of the plants themselves - the fact that the same species, *T. maritima*, grows in such different and geographically separated environments as the hot spring and salt marsh in this study suggests that they are more similar than might first appear.

The 'reference plant' developed by MARKERT 1992 makes it possible to compare the elemental content of plants in a standardized manner at the orders of magnitude appropriate to each element. As expected, it is immediately evident that patterns in elemental composition in the plants bear no relationship to those in the sediments. Regardless of species or sampling sites, the concentrations of most elements, Co, Cu, Mn, Zn, Rb, Mg, Sr, Ba, B, Ga, Pb, Y, and the lanthanides except Tb, varied less than a three-fold range compared to the reference plant. This contrasts with our expectation based on the work of REIMANN & al. 2001 that concentrations of Co, Ba and Y would show great between-species and between-site variation. It indicates that the availability of these elements did not vary greatly across the wetlands studied here and/or that the uptake and translocation of these elements into these plants and in the plants from which the 'reference plant' was derived is highly regulated. Regardless of species or sampling site, Li and Th consistently showed more than 5-fold (up to 115-fold) higher concentrations in the plants than in the 'reference plant'. This means that the wetland plant species differed in a fundamental way from the plants from which the 'reference plant' was derived and/or that the availability of Li and Th for uptake by plants at the sites studied here was higher. The Th levels in the sediments as well as in the plants at the Kyrgyz sites were much higher than at the New Mexico/Ireland sites. Although this seems to suggest that uptake of Th in plants is related to the concentrations in the sediments, it should be noted that this could simply be due to differences between the plant species. This is also illustrated by the fact that *R. pamiricus* from the Kyrgyz sites contained much higher (32-83 fold) Th concentrations compared to *P. australis*

(about 15-fold) from the same sites. Unfortunately, values for Li concentrations in the Kyrgyz sediments were not available.

In all cases, except *R. pamiricus* from Juluu Bulak, Na concentrations in the plants were much higher (7-246 fold) than in the 'reference plant'. As Markert and co-workers (MARKERT 1992, DJINGOVA & al. 2004) point out, the 'reference plant' is based on data from glycophytes, i.e. non-halophytes. It should therefore not surprise that, as expected, *T. maritima* being a halophyte adapted to saline environments (ADAM 1990), tends to take up much higher Na concentrations. *P. australis* too is adapted to moderately saline conditions (ADAM 1990), but it is unclear why *R. pamiricus* from the Tossor River contained almost 15-fold higher Na concentrations compared to the 'reference plant'. It is also unclear why *R. pamiricus* from the Juluu Bulak contained much less Na than those from the Tossor, while the reverse pattern occurred in *P. australis*.

Comparing plants from the Kyrgyz sites it is evident that in both *P. australis* and *R. pamiricus* the concentrations of Cs, Be, Ge, Se, Tb and U were elevated in the Juluu Bulak samples compared to those from the Tossor. This is possibly associated with past uranium mining in the immediate area upstream from the Juluu Bulak sampling sites. However, no sediment data were available for Ge and Se. Sediment concentrations of Be,Tb and U were similar in sediments from both streams, while Cs levels were three times higher in Juluu Bulak compared to Tossor. Rather than reflecting total element concentrations, the plant concentrations may indicate differences in bioavailability in the sediments. These observations suggest that *R. pamiricus* in particular may be a suitable candidate for biomonitoring of bioavailable pollutants originating from uranium mining. It is evident that the element concentrations in *T. maritima* from Soda Dam were typically higher than those from North Bull Island. Particularly high in the Soda Dam plants were the concentrations of Fe, Li, Cs, Be, In, Tl, Ge, As, Sb, Sc, U and W. The differences may partly be explained by the higher temperatures at Soda Dam, which would lead to higher evapotranspiration rates resulting in higher elemental uptake rates. They may also reflect differences in availability of the elements for uptake.

The accumulation to relatively high concentrations of elements such as Ge, Th and U in the wetland plant species investigated here raises the question if this is characteristic of wetland plants in general. We were unable to find other studies reporting Ge and Th concentrations in wetland plants. However, the values for U concentrations in the species reported here: 0.06 mg kg^{-1} dw in *T. maritima* from Soda Dam, 0.037 (Tossor) - 0.175 (Juluu Bulak) mg kg^{-1} dw for *P. australis* and 0.12 (Tossor) - 1.09 (Juluu Bulak) mg kg^{-1} dw for *R. pamiricus* were similar to the 0.5-2.7 mg kg^{-1} dw in the wetland plant *Eleocharis dulcis* from a uranium mining area reported by OVERALL & PARRY 2004, but much higher than the 0.01 mg kg^{-1} dw reported by MARKERT 1992. The high accumulation of Ge, Th and U in the wetland plants in this study may render those species suitable for phytoextraction or phytomining purposes (SALT & al. 1995).

In conclusion, the concentrations of several elements in the plants were very similar, regardless of species or origin, while other elements showed great variability between species and sites. Against our expectations, the Na concentra-

tions in all plant species studied here, not just in the saltmarsh plant *T. maritima*, were higher than in the 'reference plant'. Perhaps this is a characteristic of most wetland plants? Finally, the potential of the plant species studied here for phytoremediation, phytomining or biomonitoring purposes deserves further investigation.

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